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ABSTRACT

Reported were data concerned with research and development of communications systems for persons with motor handicaps. An experiment on receptive communication which attempted to determine whether tactual information could be acquired simultaneously by several fingers indicated that superior performance resulted when patterns were scanned by one finger on each of two hands. A second experiment on receptive communication investigated the relative effectiveness of three alternative symbol systems which varied the geometric similarity of symbol and referent. Results showed the greatest learning occurred when symbol and object were similar. Also reported was the construction of two prototype systems that are intended to provide a means of expressive communication for two cerebral palsied persons, one child and one adult. The system contained three functionally separate components: interface to the subject, code converter, and output display of symbols. Plans for the development of this system were said to include research on the selection of input codes, and arrangements for manufacture and distribution. (GW)

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Final Report

EC

Project No. 1-D-035
OE Grant No. OEG-4-71-0065

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COMMUNICATION FOR HANDICAPPED CHILDREN

March, 1973

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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Author's Abstract

The purpose of this project has been to develop communications systems for handicapped children. Initial work was conducted on problems of both receptive and expressive communication, but current efforts are directed toward development of systems of expressive communication--especially by cerebral palsied children and adults. Two initial experiments on receptive communication were designed to determine (a) whether tactual information can be acquired simultaneously by several fingers, and (b) the relative effectiveness of three alternative symbol systems varying in geometric similarity between symbol and referent. Two prototype systems have been constructed that will provide a means of expressive communication for two cerebral palsied persons, one a child and the other an adult. In order to permit the widest usage by persons of varying motor and intellectual capabilities, this system is composed of three functionally separate components--interface to the subject, code converter, and output display of symbols. Plans for development of this system include research on the selection of input codes, and arrangements for manufacture and for distribution to users.

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Joseph S. Lappin
Associate Professor

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March 19, 1973

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Preface

As noted in the Progress Report of September, 1971, the objectives of this project were changed slightly at that time, from an interest in problems of both receptive and expressive communication to an emphasis on developing prosthetic devices for expressive communication by persons with motor handicaps. The latter work is described mainly in Section III. Sections I and II, especially I, report work that is somewhat tangential to the current focus of this project. Some of the work reported in Section I was conducted prior to the period of funding by this grant, although it is relevant to the design of artificial communications systems. As will be evident from the reports in Sections III and IV, this is an ongoing project, concerned with research and development of communications systems for person with motor handicaps. Less empirical research has been conducted than was at first planned, simply because we have only now reached a position to design and construct the equipment that is necessary in order to actively seek out additional subjects and to conduct the appropriate research. Some of the research plans are briefly described in Section IV. We are also now near the point of discussing specific plans for the manufacture and distribution of communications prostheses.

The development of electronic and mechanical hardware, that is not only workable but also promises to be economically feasible for manufacture and distribution, has required the cooperation and contributions of several different persons and groups. I acknowledge with special gratitude the essential contributions of engineers Howard Johnston, Richard Manning, and Robert Ramsey; all have contributed considerable time, expertise, imagination, and stimulation. Gratitude is also due the Heil-Quaker Corporation, with whom Mr. Ramsey is employed, in permitting him the necessary time and freedom to work on this project. (A schematic diagram and description of the device constructed by Mr. Ramsey is included in the Appendix.) I am also grateful for the cooperation and encouragement of Mrs. Jean Stubbs, Executive Director of the Middle Tennessee United Cerebral Palsy Association. It is likely that the local UCP organization will be able to contribute some financial support for the construction of prototype systems, which will thus enable us to provide these devices for children whose parents are unable to afford the costs for the electronic components. I am also extremely grateful for the enthusiastic contributions of a large number of Vanderbilt students, both graduate and undergraduate, without whom this project would not have been possible. Although their contributions are not directly seen in most of this report they have in fact contributed a great deal of time in working not only with the subjects described in this report but also with many other handicapped children. Much of their work has not yet developed into specific findings appropriate for this report, but much of it is indirectly responsible for the results that are reported and much of it is still likely to develop specific results that will be reported later.

Table of Contents

I. Expanding the Tactual Field of View 6
Introduction 6
Method 8
Results 10
Conclusions 11
References 13

II. Communications Symbols for a Young Rubella Victim 18
Purpose 18
Method 18
Results 18
Discussion 18

III. A Communications Prosthesis 20
Introduction 20
Subjects 22
Interfacing to the subject 23
Output symbols 25
Output display devices 26
Design of the Prosthesis 28
Summary and Conclusions 29
References 31

IV. Plans for Research on Designs for Control Interfaces for Motorically Handicapped Persons 33

Appendices

A. Description of communications prothesis designed and constructed by Robert Ramsey

B. Letters from United Cerebral Palsy Association and IBM to verify cooperation

List of Tables and Figures

Table 1. Average time to read one set of patterns under each condition of finger combinations for each S. 15

Table 2. Average number of errors for one set of patterns under each condition of finger combinations for each S. 16

Figure 1. Block representation of a prosthesis for converting Morse code signals from two control switches. 32

I. Expanding the Tactual Field of View*

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Introduction

Braille is read more slowly than print. The reading rates of skilled braille readers have typically been measured at about 60 to 80 words per minute (see Nolan & Kederis, 1969); rates above 100 words per minute are rare. Skilled sighted readers, however, commonly read 200 to 400 words per minute, with rates in excess of 1000 words per minute occassionally attained after courses in speed-reading.

The principal reason for the difference in reading rates evidently derives from a difference in the number of visual and tactual characters that are simultaneously apprehended in a single "glance," rather than from a difference in the speed with which an individual character is processed. Braille readers generally utilize only one finger, usually the index finger, to obtain information from braille text (Fertsch, 1946). The available evidence indicates that this information is processed serially, one character at a time (Foulke, 1971; Nolan & Kederis, 1969). In contrast, skilled sighted readers doubtlessly process printed text in units consisting of many simultaneously perceived letters (Kolers & Katzman, 1966; Reicher, 1969). When printed text is displayed one letter at a time, the reading rate for the visual mode falls to about the same level as for the tactual mode (Troxel, 1967).

Braille is embossed in the same left-to-right sequential format as print. But this format might seem less appropriate for braille than for print, tending perhaps to limit the opportunity for sensing more than one character at a time. Although Fertsch (1946) found that many good braille readers employed both index fingers, the best readers usually read the first half of a line with the left index finger and than read the remainder of the line with the right hand. But suppose, for example, that braille were embossed with only one word on each line and that a sequence of words appeared in a vertical column down the page: Several fingers might then be used to simultaneously perceive the several characters of a given word. Braille might be read much faster if it were displayed in a format that permitted the simultaneous sensing of several characters.

The aim of this experiment was to study the possibility that several fingertips can simultaneously share in the acquisition of tactual information and to determine which combinations of fingers can most effectively cooperate in the perception or punctographic characters. Specifically, Ss were asked to read columns of punctographic stimuli (containing either one or two raised dots) with combinations of the middle and index fingers on each hand--either one finger (all four fingers were tested individually), two fingers (all six possible pairs were tested), or all four fingers at the same time.

The available literature does not provide solid ground for predicting how effectively several fingers might cooperate in simultaneously perceiving several different tactual stimuli. The basic question concerns the extent to which several fingers can perceptually function in parallel, but there seems to be no direct evidence on this question. Nor is evidence available to clearly indicate how various combinations of fingers might differ in their effectiveness.

A first question concerns the effectiveness of two fingers on the same hand vs. two fingers on different hands. Considering the neuroanatomical representation of the fingers, the most notable fact is that each hand is represented predominantly in the contralateral cortex; two fingers on different hands are thus represented in different cortical hemispheres, and fingers on the same hand are represented in the same hemisphere. But we are left with the question of whether representation in two hemispheres might facilitate parallel processing of the inputs to the two hands or whether such dual representation might require extra time to combine the two inputs, whether representation in a single hemisphere might result in mutual interference in processing multiple inputs or whether single hemispheric representation might improve the opportunity for multiple stimuli to fall simultaneously under the focus of attention. For visual stimuli, Eriksen, Greenspon, Lappin, & Carlson (1966) found no difference in the identification of dichopically presented forms when the same form was presented to non-corresponding areas of the two retinae that projected to the same or to different hemispheres; accordingly, one might expect no difference in the effectiveness of two fingers on the same hand or on different hands. Additional evidence can be obtained from experiments in which Ss were asked to judge which stimulus was presented first. Gescheider (1965, 1966) found in two separate experiments that the threshold for reporting a perceptible interval between two successive stimuli was greater for stimuli delivered to both index fingers than for stimuli delivered to the index and middle fingers of the same hand. Hill and Bliss (1968b), however, failed to find any difference between one-hand and two-hand displays in the accuracy of identifications of the order of two successive stimuli. But even in the case that temporal acuity were better for one-hand than two-hand presentations, the implication for tasks requiring the simultaneous identification of characters by each of two fingers is uncertain. Good temporal acuity might be associated with inhibitory interactions between the two fingers or with the ability to simultaneously attend to both fingers. Evidence obtained by Hill and Bliss (1968a) on the confusions in locating tactile stimuli on the four fingers on either hand indicated that the confusions between locations on the same hand are much greater than between locations on different hands. This evidence again suggests neural interactions between fingers on the same hand. The present experiment, however, did not require identification of either the temporal or spatial location of a stimulus.

Additional questions concern the use of index vs. middle fingers and the use of the right vs. the left hand. Foulke (1964) found that experienced braille readers are progressively less able to identify braille characters presented to the index, middle, ring, and little fingers, in that order. The superiority of the index finger for these Ss might, however, be due not to differences in neural representation but to differences in the perceptual training in recognizing braille characters with the various fingers. Measures of the sensory cortical areas representing the fingers (Penfield & Jasper, 1954) indicate slightly more cortical area devoted to the index than the middle finger, although the cutaneous surface area is slightly smaller on the index finger. Regarding a comparison between the fingers of the right and left hands, available evidence would suggest that there should be little difference between right and left hands. Although the majority of braille readers seem to prefer the right hand, there are large numbers who prefer the left hand and also many who read with both hands. Weinstein (1968) reported a slight tendency for lower two-point thresholds on the left side of the body, but Foulke (1964) found no significant difference between the right and left hands in reading braille.

Part of the motivation for investigating the processing of information by multiple fingers was a practical question about how to best design tactual displays. Accordingly, the method was to determine the speed with which a constant number of characters could be identified by combinations of one, two, or four fingers. Although some logical advantages would derive from holding constant the number of characters presented to each finger, such designs would be less appropriate for evaluating the advantage in reading braille with several fingers simultaneously.

The principal question is: Are two (or four) fingers better than one?

Method

Subjects.--Eight paid volunteers served as Ss. Four of the Ss were blind and four were sighted. Two of the blind Ss (S.S. and L.S.) were female students at the Tennessee School for the Blind and were experienced braille readers. The other two blind Ss (J.D. and E.C.) were male students at Peabody College; both had lost their sight in adolescence and did not regard themselves as able braille readers, although they had learned the braille code. The four sighted Ss were female students at Vanderbilt who had no prior experience with braille.

Tactual displays.--Patterns consisting of either one or two raised dots were embossed on manilla paper (approximately .18 mm thick) with a Perkins Brailler. The stimulus displays were in vertical columns of 32 patterns, arranged in 8 groups of 4 patterns each. One blank space

separated each group of four patterns and there was one blank line separating each column. The dimensions of the patterns were as specified for the standard braille code: height of each dot, approximately .38mm; base diameter of each dot, approximately 1.40 mm; horizontal separation between two dots in the same pattern, approximately 4.57 mm; vertical separation between adjacent patterns, approximately 6.35 mm. The one- and two-dot patterns each appeared with a probability of 1/2, independent of all other patterns on the sheet.

In the early portions of the experiment these columns were mounted on a board that permitted the independent vertical positioning of each column, in order to accommodate differences in lengths of the middle and index fingers; but this subsequently proved unnecessary and the uncut sheets were used as embossed by the Brailler. A large number of such sheets were independently generated. Sheets were reqlaced throughout the experiment as the patterns became worn and flattened by usage.

Procedure.--The Ss' task was to identify the number of one-dot patterns in each successive set of four patterns. Responses were made verbally--"zero," "one," "two," "three," or "four." Each trial consisted of reading eight such groups of four patterns. The main dependent measure was the time required to read eight groups of four patterns, which was measured with a stopwatch by the E. The E also checked the S's responses against the actual patterns and recorded the number of errors. The trial began with a verbal signal by E and was completed with the S made the eighth response. Arrays were always read from top to bottom, and retracing was not permitted.

There were 11 experimental conditions--four conditions in which a single column of 32 patterns was scanned with a single finger (the middle and index fingers on the right and left hand), six conditions in which two columns of 16 patterns were simultaneously scanned by a pair of fingers (each of the six possible pairs of the four fingers were tested), and one condition in which four columns of eight patterns were simultaneously scanned by all four fingers. When two fingers on the same hand were both in use, they scanned two adjacent columns of patterns, but no other restriction (other than the total width of the sheet of patterns) was maintained on the number of columns separating fingers on different hands.

All Ss participated in at least 12 sessions. During each session four trials were run under each of the eleven conditions. Two successive trials were devoted to each of the 11 conditions, and the sequence of conditions was then repeated in the reverse order. The order of conditions within sessions was balanced across Ss and across the last 11 sessions for each S.

Results

Table 1 gives the average time required by each S to read 32 patterns (by the method described above) under each condition in the last five sessions. (The data analyses are focused on the last five sessions for each S because the experimental questions are most relevant to asymptotic performance and little change in performance was evident after the seventh session.) Table 2 gives the average number of errors on each trial (out of eight responses) for each S and condition.

As may be seen, the fastest reading times were obtained in the

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Insert Tables 1 and 2 about here

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conditions in which the patterns were read by two fingers, one on each hand. The average time for the 2-finger-2-hand conditions was 9.73 sec., whereas the average times for the 1-finger, 2-finger-1-hand, and 4-finger conditions were 11.48, 11.69, and 11.38 sec., respectively. By binomial tests on the average reading times for each S in each session (a total of 40 comparisons), the 2-finger-2-hand conditions were significantly faster than each of the other three classes of conditions ($p < .001$), , two-tailed test by the normal approximation to the binomial); none of the other comparisons approached significance. Considering the error rates in these four classes of conditions, the greatest number of errors occurred in the 2-finger-1-hand conditions: The average number of errors was .99, whereas the average number of errors in the 1-finger, 2-finger-2-hand, and 4-finger conditions were .59, .61, and .80, respectively. Again using the binomial test for comparing the average errors of each S in each session, the 2-finger-1-hand conditions were significantly worse than the 1-finger conditions ($p < .001$, and the 2-finger-2-hand conditions ($p < .01$), and the 4-finger condition was significantly worse than the 2-finger-2-hand conditions ($p < .05$).

In addition, smaller but statistically significant differences were obtained between the index and middle fingers, the index fingers being faster. By the binomial test (on 40 comparisons, a two-tailed test on the norman approximation to the binomial distribution), the average reading time for the right index finger was faster than for the right middle finger ($p < .01$), the pair of index fingers was faster than the pair of middle fingers ($p < .01$), and left index finger was not quite statistically faster than the left middle finger ($p < .10$); pooling all of these comparisons, the index fingers were faster in the overwhelming majority of cases ($p < .001$). Although there was a tendency for more errors to occur in reading with a single index finger than with a single middle finger, the opposite was true for the 2-finger conditions, and the

total number of errors in all of the index-finger conditions was exactly equal to the number of errors in the middle-finger conditions. There were no reliable differences in speed or accuracy depending upon whether or not the two fingers on two hands corresponded--both index or both middle fingers.

The average reading times and average error rates were slightly lower for the right hand than the left hand, but there was considerable variability in this respect, with several Ss appearing to be consistently faster and more accurate with the left hand. Other individual differences are also apparent in Tables 1 and 2: The two blind Ss who were experienced braille readers were obviously much faster than all of the other Ss, although they also tended to make more errors. The other two blind Ss with less braille-reading experience clearly performed less efficiently than the skilled braille readers, and one was noticeably slower than any of the sighted Ss and was less accurate than three of the sighted Ss. This experiment, however, was not desitned for studying these individual differences.

Conclusions

The principal result obtained in this experiment was the superiority of performance when the patterns were scanned by one finger on each of the two hands. The discrepancy in performance when the two fingers were on one hand and when they were on two hands is surprising. The question arises as to whether the explanation should be that parallel processing was operative when two hands were used or whether mutual interference among the fingers depressed performance when one hand was used. The answer seems to be that both explanations are correct. Comparing both types of 2-finger conditions with the 1-finger conditions, the 2-finger-2-hand conditions were significantly better (by the speed measure) and the 2-finger-1-hand conditions were significantly worse (by the accuracy measure) than the 1-finger conditions. However, precise comparisons between the 1-finger and 2-finger conditions must be tempered by the fact that the distance traveled by each finger was twice as great in the 1-finger conditions as in the 2-finger conditions; the relative amounts of parallel and correlated processing therefore cannot be determined, nor can the extent of interference between two fingers on one hand be accurately measured. Nevertheless, the inferiority of the 2-finger-1-hand conditions relative to the 1-finger conditions and the similarity of the 1-finger and 4-finger conditions (requiring only one fourth the scanning distance) indicate that differences in the scanning distance for each finger were not important determinents of reading speed. The evidence for parallel processing of the inputs from the two hands is reminiscent of the suggestions, from studies of men and monkeys in whom the corpus callosum has been sectioned, that the two cerebral hemispheres can function independently as two separate centers for the conscious control of behavior (e.g., Brinkman & Kuypers, 1972; Gazzaniga, 1972). In contrast, the inferiority of the 2-finger-1-hand conditions might be taken to suggest

that the middle and index fingers on the same hand compete for limited attention by the same processing units (i.e., for common neural pathways). Such speculations await additional evidence. However, the discrepancy between the 2-finger-2-hand and 2-finger-1-hand conditions and the inferiority of the 2-finger-1-hand conditions relative to the 1-finger conditions seem inconsistent with the finding by Eriksen et al. (1966) of no difference in identification accuracy for visual forms presented to the same or to different hemispheres. Perhaps touch differs from vision in this regard, or perhaps speed measures reflect limitations not tapped by accuracy measures.

One of the purposes of this experiment was to determine whether and how one might simultaneously display tactual information to multiple fingers in a communication system. The results suggest that advantages can accrue from simultaneous stimulation of two fingers on different hands -- ideally the two index fingers. This suggestion is compatible with the frequent practice by teachers of the blind to encourage the use of both hands in reading braille (Lowenfeld & Abel, 1967). This experiment says little, however, about the specific functions in which the two hands might best cooperate. The results also suggest that little or no advantage is to be obtained from using more than one finger on each hand. Embossing braille-type displays so as to permit perception of whole words by the simultaneous functioning of many fingers does not appear feasible. Multiple fingers on the same hand may, however, be used effectively in other kinds of tactile communications systems in which the stimulation on one finger is related to that on an adjacent finger, as illustrated by Gescheider's (1965,1966) finding that the threshold for temporal asynchrony was lower for two fingers on the same hand than for two fingers on different hands.

On the other hand one finger may be added to the tactual field of view.

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Table 1

Average time (sec.) to read one set of patterns (see text) under each condition of finger combinations for each S.

Finger Combinations*

	1	2	3	4	1+2	1+3	1+4	2+3	2+4	3+4	1+2+3+4
Blind											
S.S.	4.6	4.3	4.4	4.8	5.7	4.7	5.1	5.0	5.0	6.6	5.4
L.S.	5.1	4.7	5.4	5.4	5.4	4.8	4.9	5.2	5.1	6.3	4.9
J.D.	9.0	9.5	9.6	9.8	9.7	7.1	7.2	6.8	7.1	10.2	8.7
E.C.	19.1	18.7	16.4	17.3	20.1	15.2	15.6	14.2	15.7	18.7	15.9
Sighted											
H.H.	10.8	10.6	11.0	10.6	12.5	10.0	10.4	10.0	10.0	12.8	13.4
S.B.	16.5	16.7	16.1	17.0	14.3	13.3	14.0	12.9	12.6	14.5	16.3
V.A.	13.4	12.3	12.3	12.2	11.6	9.4	9.8	9.6	9.9	10.7	12.5
V.B.	15.3	15.3	13.7	15.2	14.5	13.1	12.7	12.2	12.5	13.[illegible]	14.0
Average	11.73	11.52	11.13	11.53	11.73	9.72	9.97	9.48	9.74	11.65	11.38

*Fingers are identified as follows: 1, left middle; 2, left index; 3, right index; 4, right middle; 1+2, middle and index fingers on left hand; etc.

Table 2

Average number of errors (out of eight responses) for one set of patterns under each condition of finger combinations for each S.

Finger Combinations*

	1	2	3	4	1+2	1+3	1+4	2+3	2+4	3+4	1+2+3+4
Blind											
S.S.	1.25	1.30	1.55	1.05	2.85	2.10	1.90	1.55	1.20	3.05	2.40
L.S.	.25	.20	.20	.15	.40	.75	.45	.50	.70	.60	.15
J.D.	.90	1.15	.75	1.10	.45	.85	.75	.65	.80	.85	1.00
E.C.	1.10	.50	.70	.85	.90	.45	.70	.25	.65	.50	.50
Sighted											
H.H	.60	1.30	1.00	.80	2.05	.45	.50	.65	.80	1.40	1.15
S.B.	.10	.15	.10	.15	.50	.10	.05	.05	.15	.10	.45
V.A.	.50	.20	.05	.00	.60	.00	.20	.05	.31	.50	.25
V.B.	.10	.35	.30	.05	.35	.50	.30	.45	.45	.70	.50
Average	.60	.65	.59	.52	1.01	.72	.61	.52	.62	.96	.80

*Fingers are identified as follows: 1, left middle; 2, left index; 3, right index; 4, right middle; 1+2, middle and index fingers on left hand, etc.

Footnote

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II Communications Symbols for a Young Rubella Victim

Purpose

The purpose of this experiment was to compare three alternative symbol systems that might be used in a communications prosthesis for Jimmy, who was a five year old victim of rubella with extensive sensory and motor involvement and was described in the initial research proposal. The three symbologies used to represent common objects were Rebus, a single letter, and a sequence of three or four letters in a single word. These three sets of symbols presumably vary in their degree of physical similarity between symbol and object (being somewhat greater for the Rebus symbols than for the letters) and in the complexity of the symbol (the word being more complex than the single letter or Rebus symbol).

Method

Each of the symbols was printed on a white card. On each trial Jimmy was shown one of the cards and was asked (via sign language) to give the experimenter one of three alternative objects as designated by the card. Correct responses were reinforced with potato chips, incorrect responses received a "no" in sign language and a request to try again.

The common objects represented on the cards were wooden or plastic toys--three fruits, three animals, and three pieces of furniture. One menber of each category was represented by a Rebus symbol, another by a single letter, and the other by a word. In some sessions the three symbols were randomly intermixed for a series of trials on which Jimmy had to choose among three alternative objects in the same category (fruits, etc.), and in other sessions the type of symbol remained the same for a series of trials in which the alternative objects were from all three categories and corresponded to the same type symbol.

Results

Whichever of the above two methods was used, performance was always clearly superior with the Rebus symbols. On the first session of the experiment, performance was 78% correct with the Rebus symbols, 55% with the single letters, and 39% with the words. After a period of two weeks, performance was above 95% correct with the Rebus symbols but was still at about a chance level of 33% with the letter symbols.

Discussion

The results of this experiment indicate a surprisingly great importance of similarity between symbol and object. The result is surprising in part because of the highly schematic nature of the Rebus symbols and in part because of the failure to learn to associate the three single letters with their three designated objects. The question

about the basis for the discrepancy in performance with these two sets of symbols is also suggested by the later demonstration that Jimmy could readily identify the graphic representation for a manually presented sign, where movement was represented with red arrows and dotted outlines of the hands in an alternative position. Again there was some degree of similarity between symbol and object, but the relationship was quite schematic. Whether this apparent deficit in symbolizing ability is typical of other rubella children, and whether it can be reduced by remedial training remain to be seen.

In later work we progressed from the use of a single noun to adjective-noun and adjective-adjective-noun constructions. But Jimmy's performance with these more complex constructions was highly variable--sometimes nearly perfect and at other times barely above chance. In retrospect, this variable and frequently poor performance was probably produced by a gradual heart failure that produced the symptoms of a persistent cold.

Sadly, in August, 1971, Jimmy died of kidney and heart failure. Because our research program took a somewhat different direction at that point and because none of the other subjects with whom we have been working have been appropriate for this same kind of investigation, we have not collected any more information on this problem. We may, however, extend this experiment to another one or two rubella children who are currently in the multi-handicapped program directed by the Metro Public School System and who are currently making little use of visual symbols.

III. A Communication Prosthesis for a Quadriplegic*

Introduction

The specific objective of this project is a communications prosthesis for motorically handicapped persons. The chief target population consists of persons whose motor involvement is sufficiently extensive that they are unable to communicate by conventional means--i.e., by speaking, writing, or typing. Work thus far has been with the cerebral palsied, but is also applicable to groups with other forms of motor deficiencies. The chief objective has been to develop a communications system for expressing desires and ideas, and interacting with other people, but this problem is only a special case of the more general problem of controlling events and objects in the environment--e.g., guiding a wheelchair, opening doors, turning on a television, etc. The communication problem is not isolated from other control problems faced by the handicapped person, and solutions to the communication problem should not be considered in isolation from potential solutions to other control problems. The following work on developing hardware for a communication system is intended to be extendable to the control of other output devices.

Motor handicaps such as cerebral palsy may in general be considered as conditions that reduce the rate with which information may be transmitted by the handicapped person. The effect of the handicap is to reduce both the number of alternative positions of a particular limb and also the speed with which these alternatives can be selected. Accordingly, the selective production of specific events from a large set of alternative desired end-effects can be controlled by combining a smaller set of input signals that are repeated and concatenated to produce the larger set of outputs. The essential function of a communications prosthesis may therefore be represented as a code conversion, translating strings of input signals into another set of output symbols.

Individual users differ in both motor and intellectual capabilities; their requirements for input control interfacing and for output displays of symbols are thus also variable. The adequacy of a specific communications prosthesis depends upon its satisfying a number of criteria: (1) the input code must be matched to the motor capabilities of the user, being sensitive to those muscular responses that he can most easily produce and combine. (2) The input code, the output symbols, and their rules of correspondence must be learnable and understandable by the user. (3) The output symbols must be functionally effective in facilitating the interaction between the individual user and the various environments in which he must function. (4) The output symbols should be understandable by the largest possible

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*Based on: Johnston, H. B., Manning, R. P., & Lappin, J. S. A communications prosthesis for a quadriplegic. Proceedings of the 1972 Carnahan Conference on Electronic Prosthetics. Lexington: Office of Research and Engineering Services, University of Kentucky, 1972, pp. 25-27.

community of other persons beyond the individual handicapped user. (5) The cost and design of the prosthesis should be such as to make it available to the greatest number of potential users. In short, the design of this communication system must satisfy demands for both specificity and generality--being matched to the particular capabilities and requirements of the individual user while also being usable by a large number of persons. The required flexibility implies that the system should be modular, constructed from a number of functionally independent and interchangeable components. Specific constraints on the design of one component should not dictate the design of other components.

General aspects of the communications prosthesis design problem include (a) selection of muscular responses and transducers to detect them, (b) construction of input code words, (c) selection of a set of output symbols, (d) selection of output displays, and (e) the specific electronics for converting the input code into the output code.

Communications prostheses are currently being constructed for two subjects. Both devices should be completed and operative within at least a month. The chief difference in the two devices is in the output displays--one will utilize a visual display of up to 16 simultaneous alpha-numeric characters (a tube manufactured by the Burroughs Corporation), and the other will activate single elements in a matrix of 62 lighted characters and will also produce printed output (perhaps, for example, by an IBM Selectric). Both devices are controlled by binary input signals and use Morse code for assigning output characters to the strings of input signals.

These devices are based in part upon experience with several other prototype communications systems. The previous systems with which we have worked include (a) a code oscillator that produces two alternative tones in response to depression of two footswitches and which has been used for transmitting Morse code, (b) a random access slide projector that is operated by rotating a large selector switch to the desired one of 80 alternative positions, (c) a seven-by-seven matrix of panels in which single panels are sequentially lighted by advancing stepping switches along the rows and columns of the matrix in response to depression of two alternative switches (one for the rows and the other for the columns), and (d) an array of 33 lighted panels to sequences of two alternative signals produced by two footswitches. Of these several prototypes the last one has been the most promising and is most closely related to the system that we are now constructing. The audio device, mentioned first, is by far the simplest in design, but it is limited by its demands on the listener--that he knows the Morse code for associating letters with sequences of binary tones and that he must pay close attention to the prolonged sequence of tones. The audio output was also found to be somewhat disruptive in the classroom, especially when it was ambiguous as to whether the footswitches had been bumped accidentally or whether the

tones were being used merely to attract attention rather than to communicate something. The random access slide projector has simply not been properly suited to the motor control of the children with whom we have worked thus far. For example, one athetoid girl with whom we tried the projector has adequate motor control to operate a typewriter, and the typewriter has proved to be noticeably superior in speed and in the capability for producing printed copy. The projection of displays onto another surface has also seemed to be generally less desirable and rather more mechanically complicated and more expensive than simply turning on one of several alternative lights in a display panel. A display composed of a number of individually lighted compartments, each covered by a semi-transparent plexiglass also offers advantages of flexibility in being able to rapidly draw and erase characters with a marking pencil. The specific display matrix mentioned as (c) above has in retrospect been found to be poorly designed. Its size and weight make it difficult to move; it is connected to the control switches by long and cumbersome wires; and the response characteristics of the switches have made it awkward to use by each of the three subjects with whom we have tried it. Although this specific device has proven inadequate, the technique of activating individually lighted panels provides a number of advantages in simplicity, flexibility, and low cost. Certain variations of this display appear worth continued development and application, in ways elaborated below.

Subjects

Both subjects are female quadriplegics. Tracy is a spastic eight year old girl who is in her third year in the special education program of the Metro public school system. Tracy appears to be of at least average intelligence and is making progress in school, although her communication both at home and at school has been limited mainly to yes-no answers to questions asked by others. She is able to operate a small code oscillator that outputs two alternative tones in response to depression of two foot-switches on her wheelchair. This device has been used over the past 15 months to communicate brief messages (usually one word) by Morse code. In April, 1972, Tracy was able to transmit at a rate of approximately 1.5 words per minute.

Joy is twenty-six years of age and has had 16 years of schooling at an equivalent of an eighth grade education; intelligence testing at Peabody College has found her to have at least an average I.Q. and rather above average for C.P.'s. She is spastic with slight athetosis in all four limbs and in speech. She has been unable to sit alone, due to problems with balance resulting from the cerebral palsy, and has recently completed a spinal fusion operation to improve her ability to sit upright. Joy is currently able to communicate with her family and occasionally with some others by means of Morse code, which she indicates by moving her head in two alternative directions (one for "dots" and another for "dashes"). As a subject for whom to develop and evaluate a communications prosthesis, Joy is ideally suited because of her intelligence, knowledge of

language, and experience with Morse code. She will not require the development of training procedures and of administrative arrangements for training and testing.

Interfacing to the subject

Selecting muscular responses.--One of the most important problems in expanding the motor control of a handicapped person concerns the evaluation of the subject's existing muscular control and the selection of a set of responses to use as input to the prosthetic device. General evaluation procedures and decision rules are, however, difficult to specify. When the dexterity of the upper limbs is adequate, finger, hand, and arm movements offer a number of advantages in terms of being free to move approximately independently of the positions and activities of other limbs. There are some reasons to believe that hand movements should be utilized in virtually all cases.* The design of interfacing is also typically simpler for control by hands. Eye and head movements, foot movements, and breath control have also been utilized in similar control systems. The initial interfaces for both Tracy and Joy have utilized foot movements in a downward direction to depress or touch a switch mounted on the foot-rest of a wheelchair. In neither case have we rejected the possibility of hand-operated controls, but in both cases this will require the construction of custom-built seating to provide appropriate supports and constraints for the arms. For the present, the feet are more readily available.

Input detectors.--In conjunction with evaluation of the subject's muscular control, transducers must also be designed to detect and translate muscular responses into electrical signals. These input detectors must be compatible with the speed, accuracy, and strength of specific responses of the subject and must, therefore, be tailored to fit the individual. Spasticity, for example, may often be counteracted by designing switches that dampen the rapid erratic movements; this may be accomplished by hydraulic linkages similar to shock absorbers in a car. Spasticity in arm movements may also sometimes be reduced by reciprocally opposing one arm against the other in operating a single centrally placed lever with both hands.*

For Tracy we have thus far had most success with push-button switches mounted on the foot-rests of her wheelchair. We are now completing the assembly of photo-cell switches that are sensitive to ambient light and are thus activated simply by touch which thereby shields them from the light. For Joy we had originally planned to use her head movements to activate two micro-switches with 12-inch fiberglass levers; subsequently, however, we were surprised to discover much better control of foot movements pivoted at the ankle. Foot-switches have now been constructed that have adjustable tension and

*Personal communication. Ontario Crippled Children's Centre. September, 1972; Toronto, Ontario, Canada.

require short travel. Other interfaces that have been considered and have occasionally been used in other control systems include spectacles containing a focused light source to be directed at photo-cells, bio-electric detectors for electro-myographic signals from muscles, and a variety of magnetic, optical, and other systems sensitive to limb position.

Input codes.--The first consideration in constructing an input code is the number of alternative input signals it employs. The optimal number of input signals is determined principally by the motor dexterity and perhaps also by the intellectual development of the subject. For a fixed number of output characters it seems likely that both the ease of learning and the speed of communication increase with the number of input signals, at least for codes of up to about 25 to 50 output characters. To illustrate, many people are able to type more than 50 words per minute which is more than double the rates attained by skilled Morse code operators--the difference is presumably due to the use of a one-to-one mapping from input to output characters for conventional typewriters in contrast to the concatenation of only two inputs to produce the same output for Morse code. Unfortunately, very little evidence is available to guide the construction of optimal codes. Although it seems obvious that the optimal number of input signals for producing a given set of output characters is dependent upon the motor control of the subject, it is not so clear whether and how this might interact with the intellectual capabilities of the subject. One of the objectives of this project is to obtain evidence on the principles for constructing codes for communications systems. (See Section IV below.)

Morse code has been selected as the initial input code for both Tracy and Joy because of their very limited motor control and also because they have already been using that code. Expansion to codes constructed from more input signals is nevertheless a strong possibility for subsequent versions of communications systems for both of these subjects. Increases to just 3, 4, or 6 input signals result in large reductions in the number of repeated input signals required to produce a given output symbol.

Whatever the input code, two basic factors dictate the assignment of input code words to output symbols: First, the shortest code words should be assigned to the most frequently occurring output symbols, in order to minimize the average number of input signals. Second, some of the input code words must be assigned to control functions for the specific device (e.g., carriage return, space, erase, power off, etc.).

In one of the systems now being constructed (for Tracy) two additional foot-switches have been used to provide these control functions. In the other system (for Joy) control functions are determined by the temporal characteristics of the input signals--e.g., an inter-signal interval that exceeds some threshold will determine the end of a character.

Another important factor that determines the effectiveness of a code pertains to the demands it imposes on the subject's memory--his memory for the preceding sequence of input signals and his memory for the list of assignments of input code words to output symbols. Some codes permit a very simple graphic display of the mapping from code words to output symbols and of the sequence of responses that is required to complete and produce the next output symbol. Such factors are obviously of special relevance for subjects of lesser intellectual abilities--for young children and for the retarded. To illustrate the ways in which an otherwise complex code can be given a simple graphic representation, consider first a code with a one-to-one relation between the sets of input signals and output characters, as with a typewriter or a "conversation board." In this case each of the input switches or locations can be designated by the associated output symbol; the subject needs merely to find the desired symbol and depress that switch. The same scheme can be extended to systems with fewer inputs than outputs by means of a control function analogous to the shift key on a typewriter. A different technique for simplifying the relation between inputs needed to obtain a desired output can be illustrated by a rectangular matrix of individually lighted panels that displays the set of alternative output symbols, one in each of the separately lighted cells of the matrix, and that is controlled by two switches, one of which advances the lighted panel from left to right across a row of the matrix and the other of which advances the light from the top to the bottom within a column. In this case the subject needs to remember only the two spatial directions of change associated with the two switches. This same technique can be used to graphically represent the Morse code by simply arranging the output symbols in a binary "tree" structure; one signal then advances the light along the left branch from any node and the other advances it along the right branch of the tree for each node. In fact, this "tree" structure is more efficient in that it can be shown to produce shorter average path lengths than the rectangular matrix arrangement. The same structure can be generalized to trees with more than two branches from each node. The "tree" structure is one that we see as potentially applicable to subjects with widely varying intellectual abilities.

Output symbols

The selection of a set of output symbols is largely determined by the educational level of the subject. For subjects who can read and are able to spell, the most useful symbols are the alphabet plus additional numerals and punctuation marks. Spelling permits the generation of an unlimited vocabulary from a relatively small set of characters.

For subjects who are as yet unable to master the rather complex code for spelling words by combining letters, an alternative procedure is to represent complete words and concepts with a single symbol. The correspondence between symbol and referent can often be simplified by

the use of geometric similarity. Two examples of apparently successful applications of such hieroglyphic symbol systems are the Rebus reading program and the set of "Blissymbolics" (Bliss, 1965) being used at the Ontario Crippled Children's Centre. Although these hieroglyphic systems seem very useful in representing and teaching elementary language concepts for subjects at early educational levels, hieroglyphic symbol systems are very restricted in representing many language comcepts and in generating large vocabularies. The principal advantage of hieroglyphics might reside more in the use of a one-to-one relation between symbol and word than in the use of the geometric similarity between symbol and referent (see Rozin, Poritsky, and Sotsky, 1971). Clear evidence about the variables that determine the ease of learning symbolic representational systems is lacking, however. Premack's (e.g., 1971) work in teaching language to the chimpanzee provides a good model for selecting symbol systems that can be conveniently tied to their meaning by simple training procedures. "Conversation boards" have often not been very useful because insufficient care was taken in selecting symbols with referents that were functionally significant in training procedures for the child.

Output display devices

Output devices fall into two general categories--hard-copy units similar to typewriters and soft-copy displays. (We will here consider only visual displays of soft-copy, although audio displays are appropriate for many applications.) Hard-copy devices offer advantages in permanency of output and in displaying long strings of symbols at the same time; demands on the memory of the audience are thereby reduced. Soft-copy devices, on the other hand, enjoy advantages in cost, maintenance, portability, number of alternative output characters, and visibility of the display. Soft-copy displays also typically provide much better feedback to the subject.

One of the more readily available hard-copy units is an ASR33 teletype, which costs about $1200 and will accept standard ASCII code. Since this unit is computer-compatible, it has potential in computer-assisted training programs. Its major disadvantages are noise, short life-span, and a small character set.

More elaborate teletypes and modified IBM Selectric Typewriters are priced from $1800 to as much as $4500. Their main advantages are in greater reliability, less noise, and greater portability. Some of these units have the disadvantage of requiring non-standard input codes.

Fortunately, less expensive hard-copy units are available. One attractive alternative is a serial strip printer, which produces a long paper tape instead of a sheet with many lines of print. Such units are available for about $350 and will accept standard ASCII code without any additional interfacing. Another promising possibility is that some conventional electric typewriters might be operated by means

of relatively simple interfacing with the prosthetic device. Not only do mass production and the availability of used typewriters make this an economically feasible alternative, but the unit can also serve a double role as both standard typewriter and prosthetic device. We are currently investigating such possibilities with IBM, who has expressed a serious interest in developing such a system. (See Appendix B.)

Soft-copy devices offer many advantages over hard-copy units, although they suffer from the lack of a permanent record and thereby require the presence of an attentive audience. The simplest, least expensive, and most flexible units are capable of displaying only one symbol at a time, each of which is located in a different position in a display of individually lighted panels. The flexibility of such a unit is provided by the ability to change symbol sets by simple drawing a new character on the semi-transparent cover over each light. Thus, the same unit can be readily adapted to the needs of different subjects of widely varying intellectual abilities and to the requirements of different social settings in which communication occurs. As discussed above, the best general design would seem to be a "tree" structure in which symbols are positioned at the nodes of a branching hierarchy. One such display to be used by Joy contains 62 symbols--26 letters, 10 digits, and punctuation marks, commonly used words, and special characters.

Three additional types of soft-copy devices display several characters simultaneously, and thereby eliminate the requirement that the audience attend to each individual symbol as it is produced and remember the preceding series of symbols. First, displays are available from the Burroughs Corporation that are capable of presenting up to 256 characters. The cost ranges from $260 for a 16-character display to $1100 for the 256-character unit. These units accept a seven bit ASCII code, including an erase function, and are small in size. We are near completion of a device for Tracy that will utilize one of these 16-character displays.

A second alternative is a display of say 10 or 20 characters constructed from 5 x 7 arrays of light emitting diodes (LEDs). Such a unit can be driven with the same input code as with the Burroughs tubes, but is capable of a much larger character set (e.g., hieroglyphics.) Such a unit would cost more than the Burroughs tube in single quantity purchases, but can be quite feasible in quantity purchases.

A third alternative is a cathode ray tube display. This approach can provide the greatest number of alternative output symbols, but is also the most expensive and least portable of the multi-character displays. The availability of low-cost CRTs and read-only memories (ROMs) for generating characters make this approach worth exploring, though we have not yet determined the cost/effectiveness trade-off.

Design of the Prosthesis

The communications prosthesis should satisfy several criteria: First, it should be small, light-weight, portable, and preferrably battery operated. These conditions are especially important for ambulatory subjects. The chief disadvantage of most hard-copy output devices is that their lack of portability restricts operation to a fixed physical location. Second, the prosthesis should be inexpensive, reliable, and easy to maintain. Third, the system should be adaptable and expandable to a variety of input codes and output symbols. The requirements and constraints upon the communications system are widely variable from one subject to another and from one social environment to another. The population of nonverbal persons for whom this prosthesis might be desirable are widely variable in motor and intellectual capabilities. The variety of environmental settings in which communication should occur--e.g., a classroom involving interactions with the teacher and with other students, parent-child interactions, patient-attendent interactions, completion of homework assignments by the individual, etc.--impose varying demands on the subject-matter content of the communications and on the means by which the symbolic outputs are displayed.

Low cost and low power consumption can be achieved by the use of integrated circuits (ICs). These are small in size, light in weight, and are also very reliable and easily maintained.

The adaptability of the system to variations in input codes and output displays is determined by the logic of the intervening code converter for mapping input to output. Without discussing the alternative designs that have been considered, the logic that we have chosen for the code converter component of the prosthesis being constructed for Joy is represented in the block diagram in Figure 1. (A slightly different design has been employed by Robert Ramsey in the device that he is constructing for Tracy; this is described in the Appendix.) The design of available digital logic components demands that each input signal be initially encoded as a binary code. (Such encoding is, of course, unnecessary when the input is presented on two alternative switches as in the specific device now being constructed.) These sequential strings of input signals are first converted from serial-to-parallel by a shift-register into a unique n-digit binary code for each input code word. These binary coded input words are then converted into one of the standard codes for controlling the output device--e.g., ASCII, EBCDIC, or IBM Selectric--by means of a field programmable ROM, such as the "intel 1701" (available from the Intel Corporation for about $80-$100). This last component is extremely flexible, since it can be erased by exposure to ultraviolet light and then be reprogrammed. For later less experimental devices, requiring less flexibility, preprogrammed ROMs are available at a cost of only about $15. For some output devices, such as the 64-light display described above, that require one of 2^n different outputs, the code conversion can be done more directly by means of a matrix or grid decoding structure.

More specifically, our Morse code input has a maximum word length of five signals. A "dot" is stored in the shift register as a zero and a "dash" is stored as a one. At the end of a character a unique six-bit binary number is represented in the shift register. (The sixth bit is necessary since this is a variable-length code.) The output of the shift register is transferred in parallel to the ROM and also to two 3-to-8 decoders that are mapped into an 8 x 8 matrix which in turn provides one of 64 outputs by the coincidence of any row and column. The logic design shown in Figure 1 requires few ICs. 24 IC packages are required for the 64 light display; if teletype output is included, then the ROM and a parallel-to-serial converter (about five additional IC packages) are required.

The total cost for the parts for this system, including input switches, and 64-light display, is about $300 for single quantity purchases. With quantity purchases and other discounts that might be given for a project such as this, the cost can easily come within the reach of nearly all potential users.

Considering longer range plans for even more flexible and powerful devices that would be capable of controlling a wide variety of devices in the environment--e.g., wheelchairs, appliances, and other equipment for training and employment---it is now quite realistic to seriously consider replacing the simple code converter in Figure 1 with a general purpose micro-computer. Within the past three months such computers, embodied in a single IC and weighing only a few ounces, have become widely available at very low cost. Even in single quantity purchases, the cost of the computer alone can be about $100 (e.g., the MCS-4 from the Intel Corp.); with additional required buffer memories and ROMs for input/output interfacing the total cost is about $500. With quantity purchases and further development of the market the cost will be still lower.

Summary and Conclusions

A communications prosthesis may be considered as a system for converting a small set of alternative motor responses from the subject into a display of a larger number of alternative output symbols. There are three functionally separate components of this system: interfacing to the subject, code converter, and output display. The greatest costs are encountered at the output displays. The greatest uncertainties about design and the most likely source of problems in the effective operation of the device, involve the interfacing to the subject. The uncertainties about the proper designs for the interface to the subject are concerned with determining the motor capabilities of the subject and then identifying the most effective mechanical and electronic interface for translating the subject's responses into electronic signals; the motor control exhibited by the subject is heavily dependent upon the specific mechanical devices he is manipulating, upon the seating arrangements that determine posture and constrain other limbs, and upon the sensory feedback provided to the subject about the effects of his

movements. (See Section IV below for plans to investigate this problem area.) In providing communications systems for young children or for persons with other learning disabilities, there is an additional question about the most desireable form of output symbols.

We have now completed two specific communications systems, each involving slightly different designs for each of the three main components. The costs for these devices should make them available to practically all potential users. Initial contacts have been made about means for the manufacturing and distribution of these systems--through IBM, United Cerebral Palsy Association, and other local groups.

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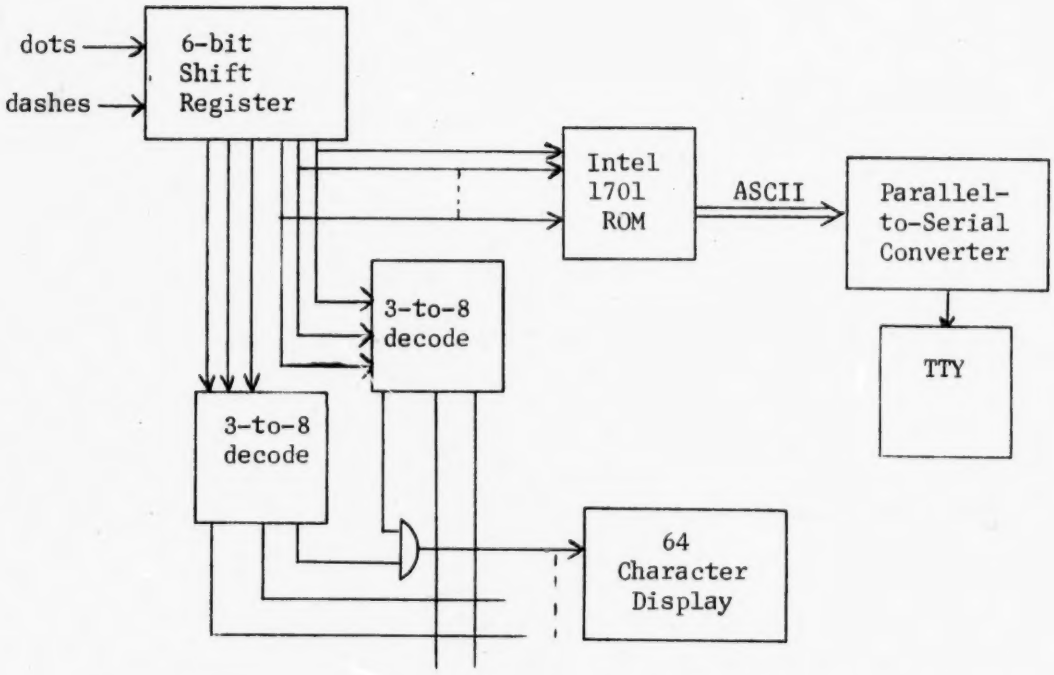

Figure 1. Block representation of a prosthesis for converting Morse code signals from two control switches.

IV. Plans for Research on Designs for Control Interfaces for Motorically Handicapped Persons

The research described below was planned about eight months ago, but has not yet been carried out due to unanticipated delays in constructing the required interfacing for the small computer (PDP-8I) that will be used in the experiments. The experiments are directly related to the objectives of this research project; some of these experiments would have been conducted by this time had the interfacing been available in June, as originally expected. The computer interfacing is now almost finished; the initial experiments should be in progress within less than a month.

The experiments are directed toward three general sets of questions: (1) How do the rate of learning and asymptotic speed of performance for producing some fixed set of output characters (e.g., the 64-light display of the prosthetic device in Section III) depend upon the number of alternative input signals, and how does the optimal number depend upon the motor and intellectual abilities? (2) What measures of the subjects' movements (i.e., variations in positions, times of occurrence, force, or velocity) can be most effectively used to encode the input information, and how does the optimal combination of such measures depend upon the motor capabilities of the subject? (3) Can greater control over a particular response measure be obtained by the use of additional sensory feedback?

The experimental apparatus that is being constructed consists of an output display of 64 lights in a rectangular matrix and an input interface for the subjects' responses that is activated by a variable number of switches that vary in size and location. A small laboratory-control computer (PDP-8I) is used to control the visual display, to measure the speed, position, and force of the subjects' responses, to control the coded mapping from response switches to visual outputs that determines the "correct" response for a given output, and to deliver feedback to the subject. In a typical experiment, the subject would first be trained in the use of a particular code rule for producing the set of outputs with the available response switches and his speed in producing a given set of output characters would then be measured. A trial might begin, for example, by the computer activating a particular light in the display and the subject would then attempt to turn the light off as rapidly as possible by making the appropriate series of responses. The two general criteria for the efficiency of the subject's performance with any given code rule are the rate of learning and the asymptotic speed of performance. Both normal and motorically impaired subjects will be tested.

The first experimental question listed above is prompted by the absence of evidence about the rules for constructing efficient codes for expressing and symbolizing information. It seems likely that for the normal operator codes are more rapidly learned and produced when

there is a one-to-one relation between input and output characters, at least for up to about 50 output characters. For lists of output characters that are in excess of a 100 or so items, then even the normal operator is rather certain to find it easier to encode these by combining the elements of a smaller alphabet of input symbols. Rather certainly, too, the motorically handicapped operator can more efficiently utilize a code constructed from a smaller number of input symbols, but beyond this it is difficult to make any generalizations with confidence.

The second set of experimental questions is prompted by the possibility that many handicapped persons might more effectively control the temporal characteristics of a small number of responses than to produce the same number of input signals by moving a given limb to several different spatial positions. We need to determine whether this is the case for the two subjects described in Section III, for example. Control interfaces can be easily designed and implemented in which the device itself oscillates between two or more values of a specific input signal and the subject then selects the desired alternative simply by depressing a single switch at the appropriate point in time. This is, of course, more similar to the standard use of Morse Code, in which the duration of the operator's response determines the value of the input signal, than is the two-switch encoding we are currently using.

The third set of questions is stimulated by the recent suggestions of several researchers (Bonwit, et al., 1972; Harris et al., 1972; Morrison, 1972; Wooldridge, 1972) that many cases of poor neuromuscular control can be greatly improved by the use of supplementary sensory feedback to the subject about the positions and movements of his limbs. Insofar as this possibility exists, then the prosthetic control systems described in Section III offer an excellent opportunity to illustrate and capit alize on the possibility. Moreover, the answers to the two sets of questions described above are dependent upon this possibility of improving the subject's motor control.

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Appendix A

Description of communications prosthesis designed and constructed by Robert Ramsey

MORSE CODE SIMULATOR ©

The purpose of this undertaking was to build a low cost Morse code simulator for handicapped persons. Two prototype experimental units were constructed and proved very successful.

The first was completed in February, 1972 and used solid state silicon controlled rectifiers (SCR) in a modified ring counter circuit. These SCR counter elements were arranged in TREE configuration (Fig. 3) to conform to the International Morse code. Four input pedals were used: from left to right, 1) START or reset, 2) DOT, 3) DASH and 4) DISPLAY or print. It is intended to use print-display command to start a teletype, CRT, or other character storage display. The first model has 26 letters, 10 numbers, 10 special characters, blank, and one control element. This 47 character set was accomplished using 26 counter circuits by wiring one-half of the set in the background. Using four input pedals, timing by the user was avoided. Gates were provided to eliminate contact bounce and operator error.

The second model was completed using 16 counter circuits, a small TREE and row-column output providing 63 characters in a 7 x 9 matrix (Fig. 4). An output conversion was added to convert to ASCII for a Burroughs scan panel. This device stores 16 characters entering right to left, shifting with each display command. This allows simple sentence display or continuous information display and is small, light and portable.

The selection of Morse code was difficult. It has the advantage of relatively easy learnability, fewer operations for frequently used letters, i.e., E, T, A, and N; but disadvantages of timing required for word and letter spacing. This was overcome by using four input pedals. The unequal character lengths of Morse code prove very difficult and costly to convert directly;

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however, this was overcome with the unique TREE counters and row-column conversion to a standard code (ASCII, etc.). The cost of the TREE counter is nominal, say $1.00 per circuit. The displays and code converter are the remaining cost items (for the Burroughs, $270) leaving the cost per system less than $500.00.

The standard ring counter (Fig. 1) works as follows: when power is applied at +, all lamps are off. A reset pulse through diode D_R will cause gate G of SCR_1 to fire, conduct and latch the SCR on, causing the anode to go low and the $Lamp_1$ to light. This lamp will remain lit until power is removed or this SCR is commutated by the second SCR. After reset and $Lamp_1$ is lit, a pulse at the input count line will cause SCR_2 to fire, turning on $Lamp_2$ and turning off $Lamp_1$. The second pulse will cause SCR_3 to fire and turn off SCR_2. The same thing will happen on pulse #3, turning on SCR_4, $Lamp_4$, and turning off SCR_3 and $Lamp_3$. This can be extended to any number of ring counter circuits. The circuits, except for the reset, are all the same and will be used exactly in the unique TREE counter except two input lines will be used, one for DOTS and one for DASHES.

The method of selection of the SCR in the string to be turned on is of interest. If SCR_1 anode A is low, then D_1 is near forward bias; however, all other diodes are heavily reverse biased by the resistors when the preceding SCR anode is high. Therefore, only the diode following the SCR that is on can conduct from the pulse line, thus turning on the next SCR.

The capacitor C_A commutates the on SCR by forcing a reverse charge on the previous SCR anode.

It should be noted that SCR's were selected because of their ability to store or latch, their relatively large current capacity, and the easy circuitry for the ring counter. These SCR ring counters can be arranged in a simple matrix, say 8 x 8, for those not wishing to use Morse code.

We would recommend a circuit similar to Fig. 2 with one input for rows and one for columns.

Figure 1. RING COUNTER (STANDARD)

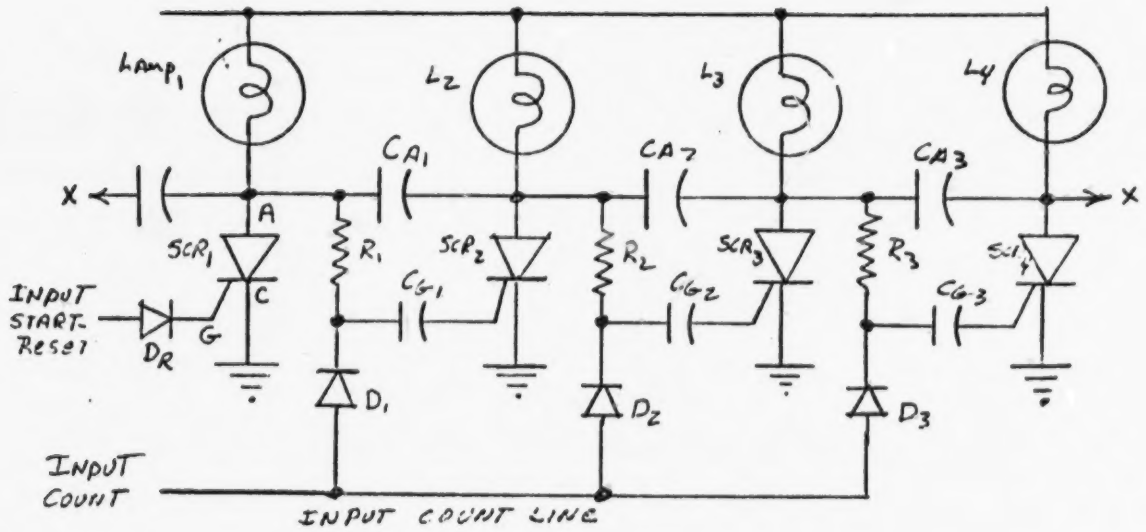


Figure 2. MATRIX COUNTER (ROW x COLUMN)

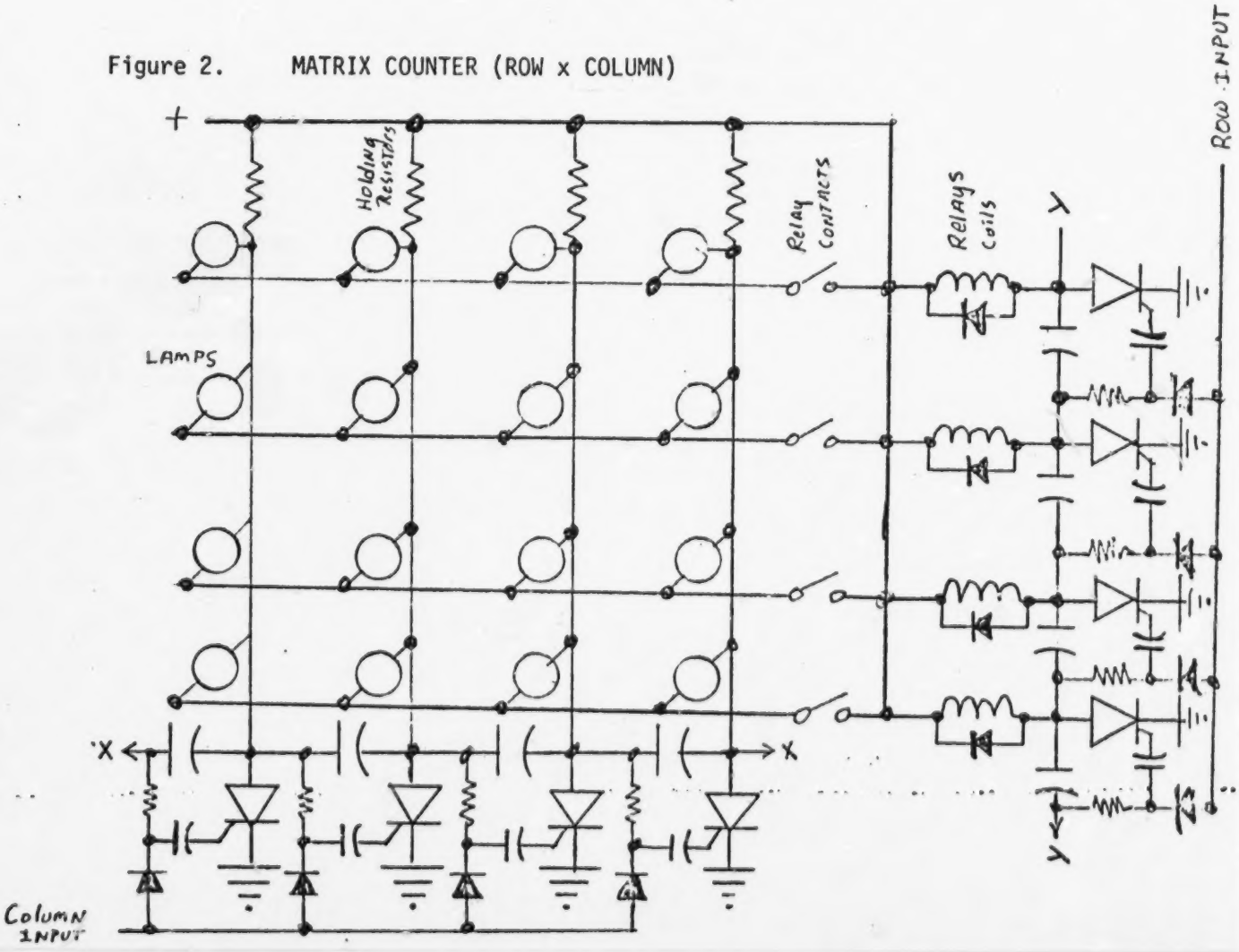
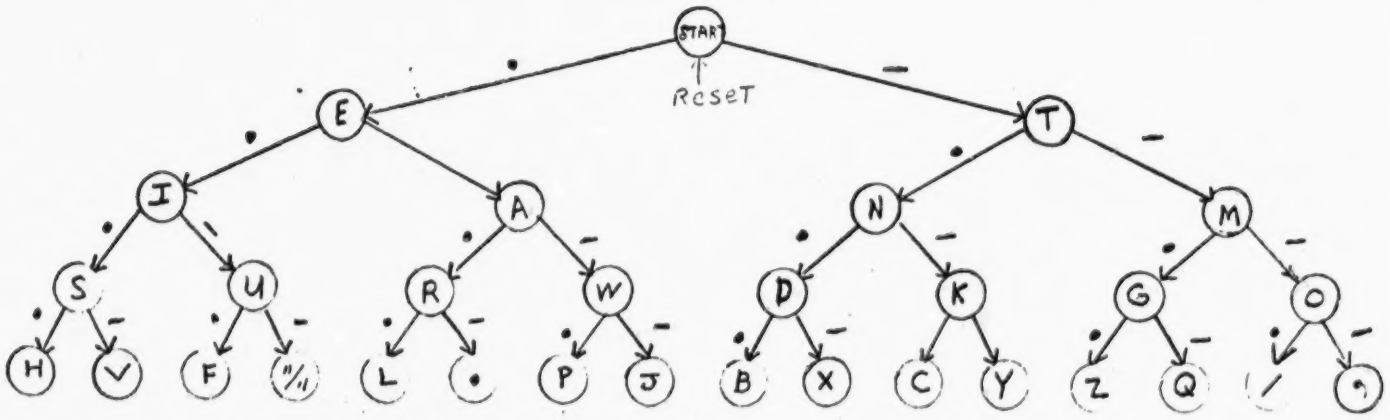


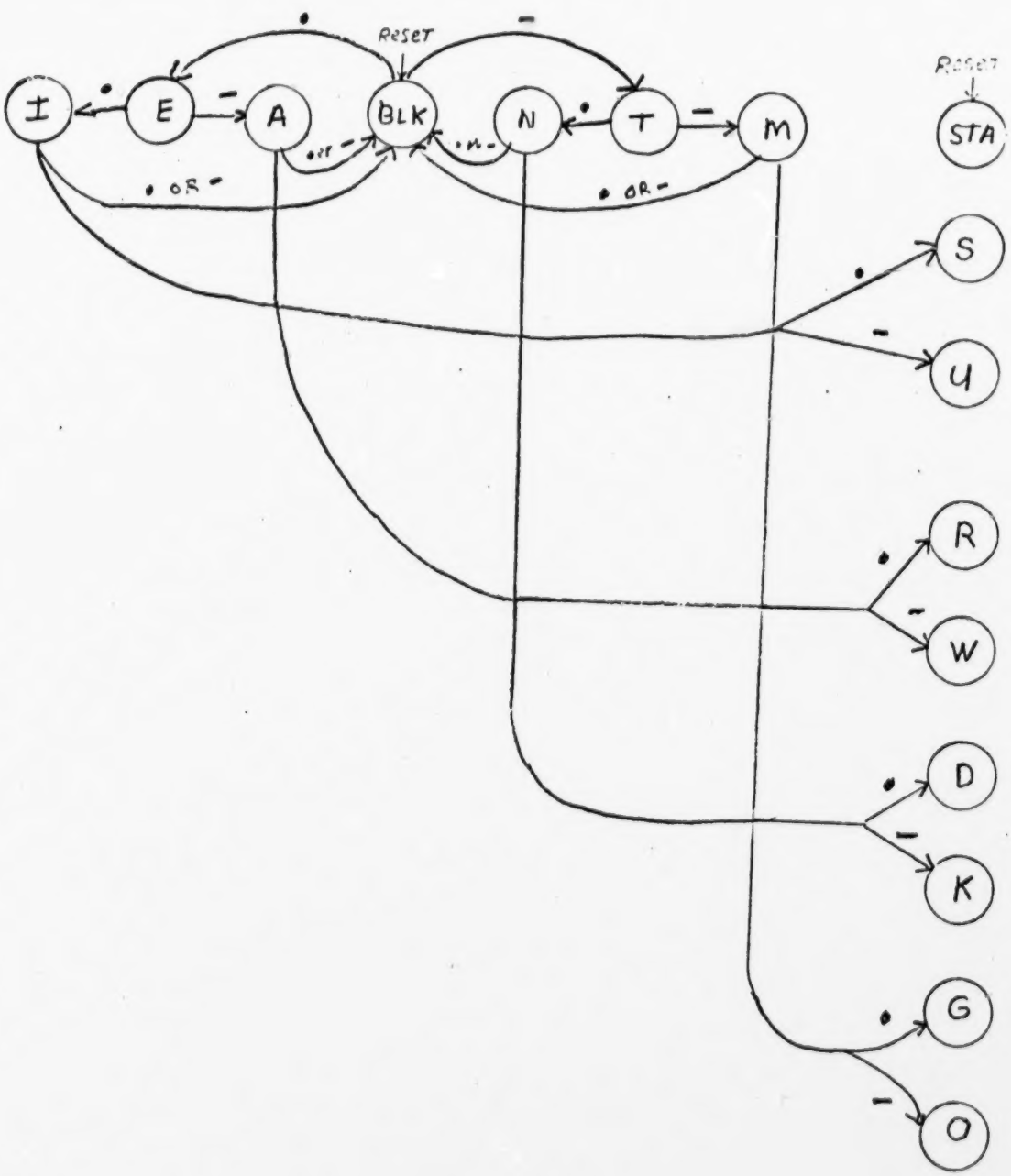
Figure 3. BASIC TREE COUNTER



Shown above is the TREE counter used in the first experimental model. The lights were arranged as above for a learning tool. Only the counter circuits on the left were constructed. All letters on the right were activated by using SCR TREE counters on the left, using a common line latched line off the "T" SCR. The left dot (·) input pedal feeds all (·) diodes on the counters, but only the SCR that has a feeding SCR resistor low can fire, i.e. to send a letter "R", the count begins at "START" which sets up the "T" and "E", but if a (·) is sent, the "E" lights, setting up "I" and "A", then a (-) will light "A", thus setting up "R" and "W", then a (·) will light "R". If then a display is inputted and proper code conversion is available, the "R" can be stored on a display and the operator moves to the next letter.

On the second model, the TREE counter was reduced to 7 SCR's and simple storage in 9 other SCR circuits. This was to reduce the number of parts and to provide more characters (63). It was arranged as follows:

Figure 4. SMALL TREE COUNTER WITH ROW STORAGE



After reset, the TREE count starts with Blank (BLK) and Start (STA) on. A (·) yields an "E" (Start still on). The selection is now "I" or "A" as before. The second (·) yields an "I" (STA still on). The selection is now "S" or "U". The third (·) yields an "S", "BLK" and turn off "STA". A fourth (·) yields "S" and "E". The fifth (·) yields an "S" and "I". This is the end of a five level code which is all that is required for International Morse and 63 characters.

Notice, all one and two level characters are in row one, called "STA". All three level characters are in rows 1 through 8. S, U, R, W, D, K, G, O under BLK. All four level characters are in these same rows under Column "E" or "T" and all five level characters are under "I", "A", "N", and "M". This suggests a reinforcing light system row by column requiring only 16 lights of display. (The basic TREE is still recommended for learning.)

This forms the 7 x 9 matrix with two lamps always on. More examples of the 4 and 5 level displays are "H" reinforced under "E" and "S" and 5 (·····) under "I" and "S".

The "ROM" address (Fig. 5) forms the remaining characters. These can be changed to meet the requirements of the user.

A programmable read-only-memory was planned for the conversion to ASCII from the 7 x 9 Morse display. We later built a diode matrix using TRI in-state hex inverters to select the diodes set. As this is a lot of labor, the PROM would probably be the best selection. In a 256 x 8 bit PROM, four codes can be stored, i.e., ASCII, Selectric® (IBM), EBCDIC, BAUDOT. The output could then be selected manually for the display system used. Only 6 bits are used for the input address, leaving bits 128 and 64 for code selection, via a manual switch.

fig 6 SPOOKY SYSTEMS BLOCK DIAGRAM (PRELIMINARY NOV 29, '72 R. Ramsay)

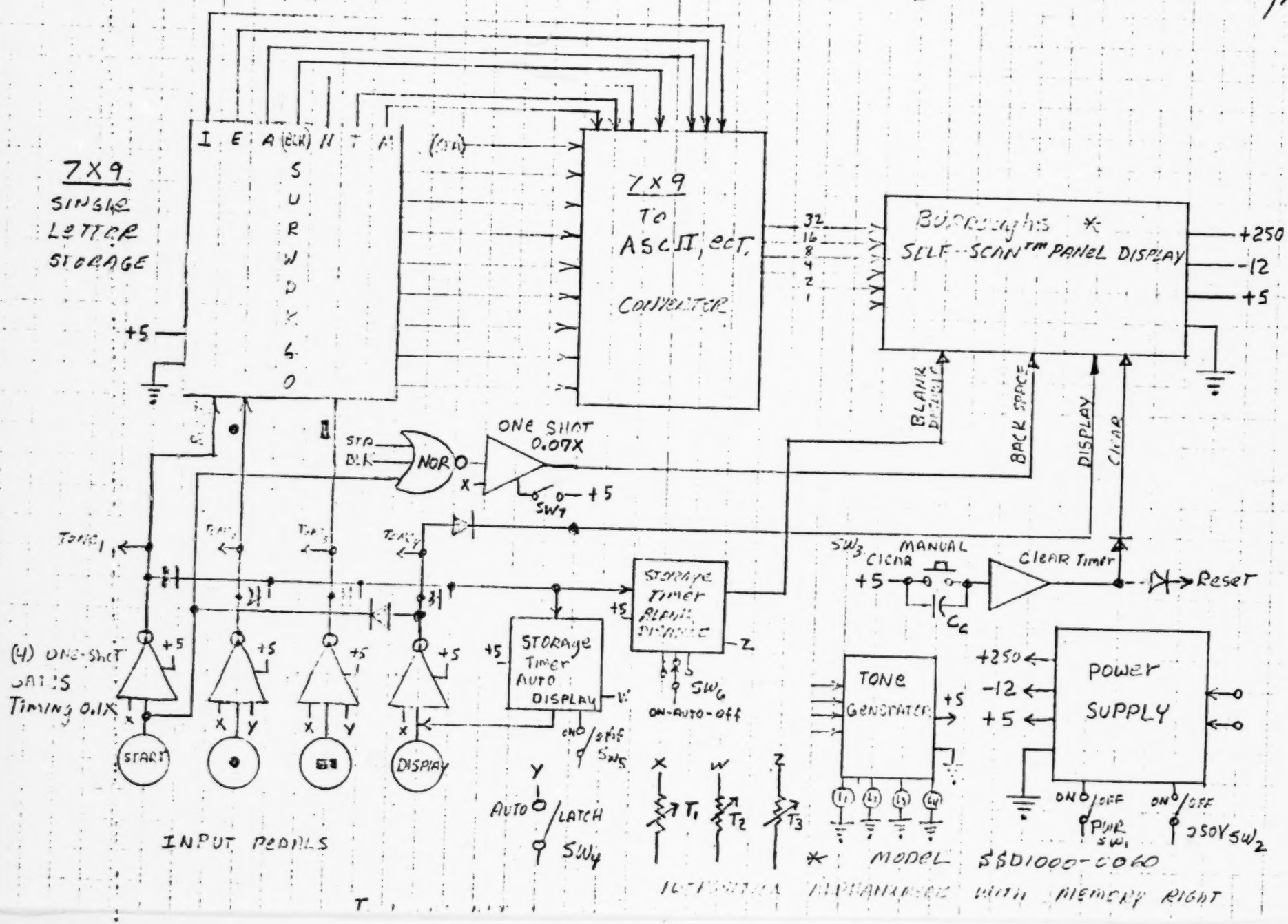


Figure 5.

PROM - ADDRESS (Neg. Logic)
(7 x 9 Ramsey Matrix)

Appendix B

Letters from United Cerebral Palsy Association
and IBM to verify cooperation

International Business Machines Corporation

New Circle Road
Lexington, Kentucky 40507
606/233-2000

March 14, 1973

Dr. Joe Lappin
Department of Psychology
Vanderbilt University
Nashville, Tennessee

Dear Joe,

In response to your request, we are sending you a used "Selectric" 735 Input/Output Typewriter to serve as the output unit for the prototype machine you are developing for use by handicapped persons. In addition, we shall forward some schematics to assist you in fully utilizing the equipment.

IBM views your undertaking as a very worthwhile endeavor and, with the understanding that no commercial exploitation is intended, is providing the machine free of charge on a permanent loan basis, i.e., IBM maintains title to the machine and reserves the right to recover possession in the event that the above stated conditions are breached. However, the machine is yours to use as needed for your handicapped program.

In addition, as you and I discussed, offering this one machine should not be misconstrued to imply any commitment on IBM's part to supply machines or material in the future. However, we are interested in the work you are doing and request that you keep us abreast of your developments. When you are prepared to proceed to full scale evaluations, or production of your handicapped machine, we would like to discuss your program with you.

Best of luck to you, Joe.

C. R. Thomas
Product Planning Representative
Used Equipment

United Cerebral Palsy

CECIL SIMS CENTER
OF MIDDLE TENNESSEE
337 22ND AVENUE, NORTH • NASHVILLE, TENN. 37203

TEL. 327-2961

March 12, 1973

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Professor Joseph S. Lappin
Psychology Department
Vanderbilt University
Nashville, Tennessee 37240

Re: Status of proposed plans for providing funds for construction of communications prosthesis for cerebral palsied persons.

Joe:

This note is to verify our desire to cooperate with you in constructing and evaluating communications aids for cerebral palsied persons. Our Professional Advisory Committee has recommended that the Cecil Sims Center provide up to $300 for the construction of each individual device, according to the guidelines discussed at our meeting on November 1, 1972. Due to financial considerations unrelated to the quality of this project the Board of Directors has not yet been able to give final approval for specific funds, but we are nevertheless anxious to assist in making these communications aids available to cerebral palsied persons.

Sincerely,

Mrs. Jean Stubbs

Mrs. Jean Stubbs
Executive Director